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NASA TECHNICAL MEMORANDUM

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INVESTIGATION OF FATIGUE PROBLEM IN 1-MIL DIAMETER THERMOCOMPRESSION AND ULTRASONIC BONDING OF ALUMINUM WIRE

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16. ABSTRACT

This memorandum is the result of investigation into the failure mode caused by thermal deformation and how it affects bond integrity.

Thermal analyses at various working conditions were conducted in actual transistors and analyses with the Scanning Electronic Microscope (SEM) were performed.

Based upon the results of these tests, it was possible to establish to what extent thermal fatigue influences the reliability of transistors using 1-mil aluminum (Al) wire thermocompression (T. C.) wedge or ultrasonic bonded.

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INVESTIGATION OF FATIGUE PROBLEM IN 1-MIL DIAMETER THERMOCOMPRESSION AND ULTRASONIC BONDING OF ALUMINUM WIRE

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SUMMARY

The failure mode discussed in this memorandum is presented with the objective of enabling the engineer and designer to become as familiar as possible with fatigue failure that involves bond reliability as related to temperature. It is estimated by some authorities that 90 percent of all fatigue failures are not caused by faults in the material itself, but by faulty detail design, improper handling equipment, or lack of adequate inspection.

Exhaustive tests are required to determine the fatigue strength of 1-mil aluminum (Al) wire thermocompression (T.C.) wedge or ultrasonically bonded to a silicon chip; however, it is known that abrupt changes in cross-section, due to the bonding operation, cause a significant reduction in fatigue strength. Such a change in cross-sectional area is found at the heel of the bond, and metal fatigue caused by thermal deformation usually breaks the wire at this, the weakest point.

SECTION I. INTRODUCTION

The purpose of this memorandum is to illustrate the failure mode caused by thermal deformation and how it affects bond integrity. Wedge and ultrasonic bonding in small-signal 1-mil diameter Al wire transistors is the subject of this work. Repeated switching of the transistor between high and low power, at a rate that allows thermal expansion and contraction in the interconnecting wire, causes the wire to flex at the point of reduced cross section until finally the wire breaks due to metal fatigue. It was noted that the thermal deformation was related to many factors such as transistor power dissipation, current density in the wire, wire dress and length, thermal time constant, and frequency of operation.

To verify the existence of these factors, thermal analyses at various working conditions were conducted in actual transistors, and analyses with the Scanning Electronic Microscope (SEM) were performed. The effects of wire dress were investigated using a wire connected between two posts, subjected to various combinations of current density and cycling time. Based upon the results of these tests, it was possible to establish to what extent thermal fatigue influences the reliability of transistors using 1-mil Al wire T.C. wedge or ultrasonic bonded. The failure mode was identified as cracking and separation of the bond wire at the heel of the bond.

Subsequent to the identification of the failure mode, it was determined that the mode could be eliminated by changing the type and/or size of the interconnecting lead wire and changing the method of bonding to eliminate the necked-down condition.

In April 1969, a screened 2N2222A transistor with date code 6807, failed in the Electronic Control Assembly (ECA), Ignition Phase Timer during testing, prior to hot firing of a J-2 engine at the Rocketdyne engine test stand. The timer was removed from the ECA and analysis showed that the 2N2222A transistor was open between base and emitter. The failed transistor was decapped by the manufacturer, and visual inspection revealed that the base interconnecting lead wire had fractured at the heel of the T.C. wedge bond to the semiconductor chip. (See figure 1.)

To investigate further, MSFC conducted a study of the problem, its causes, extent, and the possible screening tests and inspections.

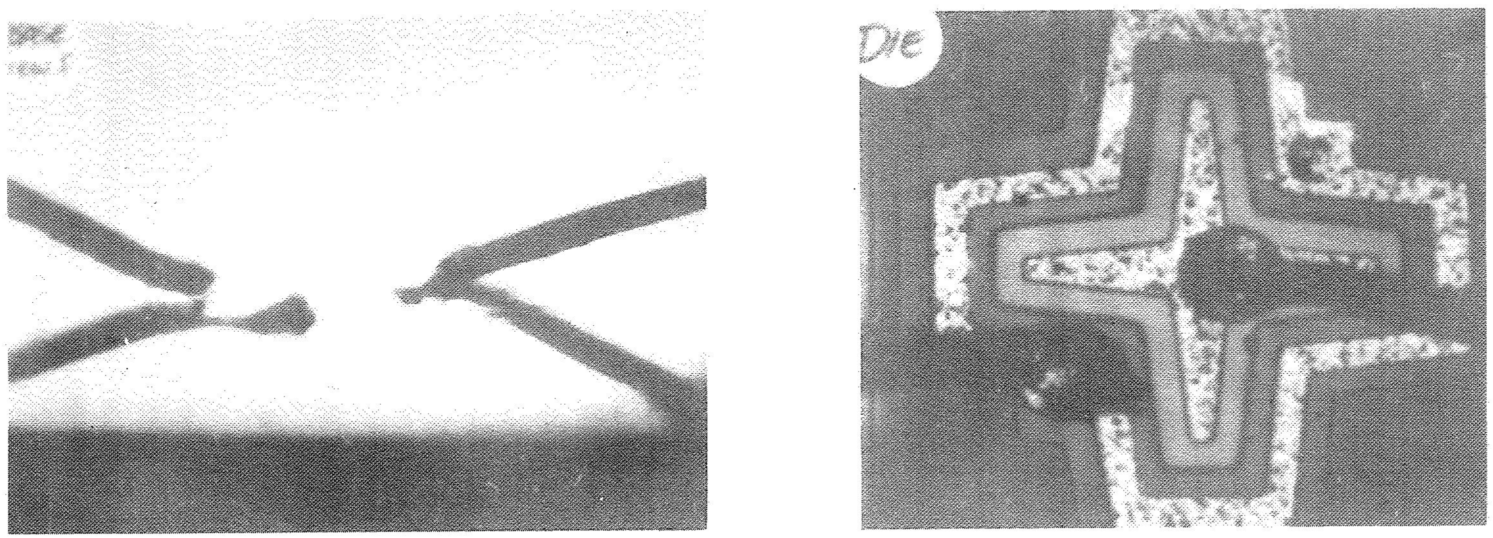


Figure 1. 2N2222A Transistor From The J-2 Engine Phase Timer

SECTION II. INVESTIGATION CRITERIA

A. FAILURE MODE

Since the failure was mechanical in nature, namely cracking and separation of bond wire at the heel of the bond, it was believed that accelerated stress testing such as power cycling was the best approach to evaluate bond integrity, and to duplicate the failure mode and mechanism of the failed transistor.

MSFC conducted power cycling tests at maximum rated power of the device with a collector current of 50 mA and repetition rates below 1 Hz on a sample of seven transistors T. C wedge bonded. Four transistors failed catastrophically. The devices used for this test were decapped and analyzed with a SEM. The SEM analysis of bonds that had not failed revealed that the Al interconnecting leads were greatly reduced in cross-sectional area at the heels of the bonds. Examination of the failed bonds showed that the separation occurred at the reduced cross section. (See figures 2 through 7.) The rough appearance of the wire in the areas of separation indicated a fatigue fracture mechanism as described in Motorola report, "Frequency-Power Dependence of Mechanical Failures in Transistor Bonding Wires."

B. THERMOMECHANICAL EFFECT

It is known that abrupt changes in cross section of the wire, due to the bonding operation, cause a significant reduction in fatigue strength. This is further discussed in MSFC memorandum S&E-ASTN-ASR-69-60, which states the following: "Analysis indicates that the high temperature thermocompression wedge bond creates local plastic hinges at the heel of the bond which plastically deform under very small loads. Because of electrical clearance requirements, a sharp local vertical rise is also formed at the heel during the bond. This rise causes misalignment of the center lines in a region of varying cross sections. The stress concentration effects, residual stresses, and material property degradation negate the development of an endurance limit (threshold stress below which an infinite life cycle may be achieved). The high ductility of the region allows large deformations without fracture. However, reversal of the strain on each cycle results in creep and reduction of the cross section area on each thermal excursion until cracks form and failure results."

220X

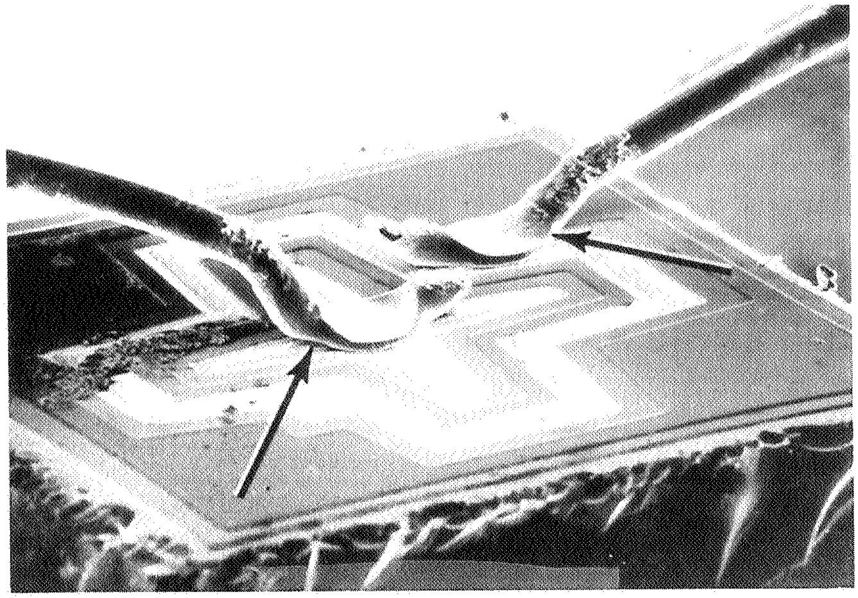


Figure 2. Manufacturer "A" 2N2222A, From Ignition Phase Timer, Typical T. C. Wedge Bond

300X

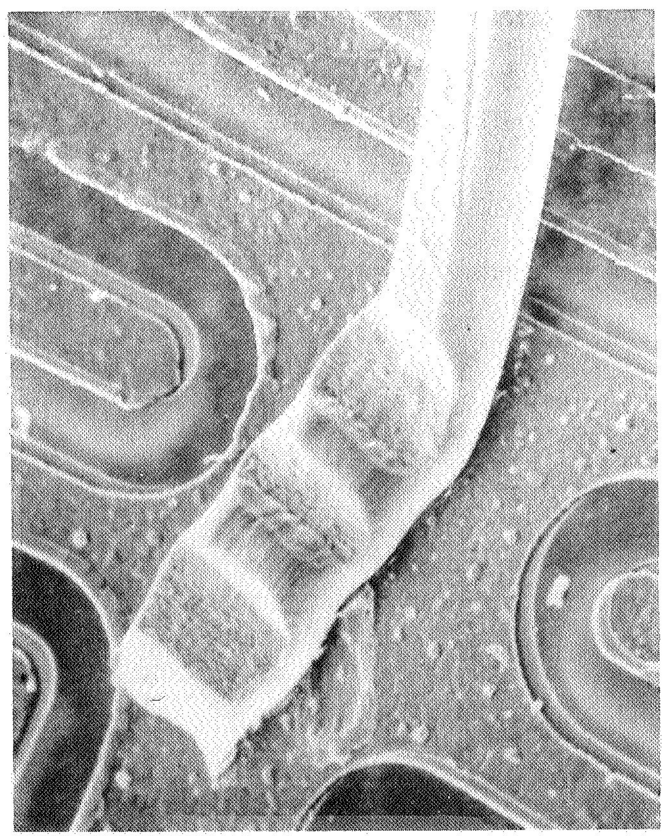


Figure 3. Manufacturer "B" 2N2222A, Typical Ultrasonic Bond

Base, 5200X

Emitter, 2300X

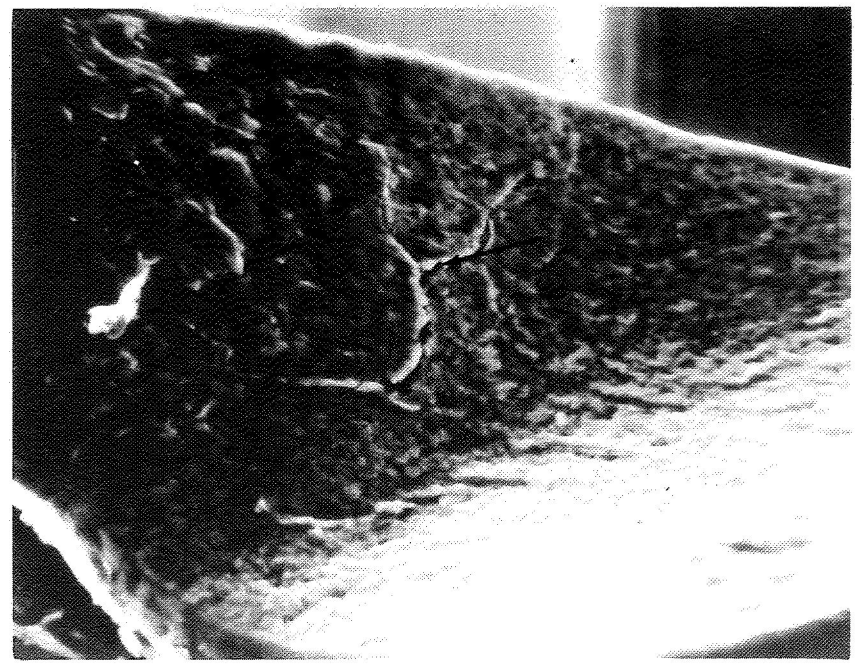


Figure 4. NA5-27473T (2N2222A), T.C. Wedge Bond, Die Side Bond, Microcracks at the Heel Before Power Cycling

2000X

500X

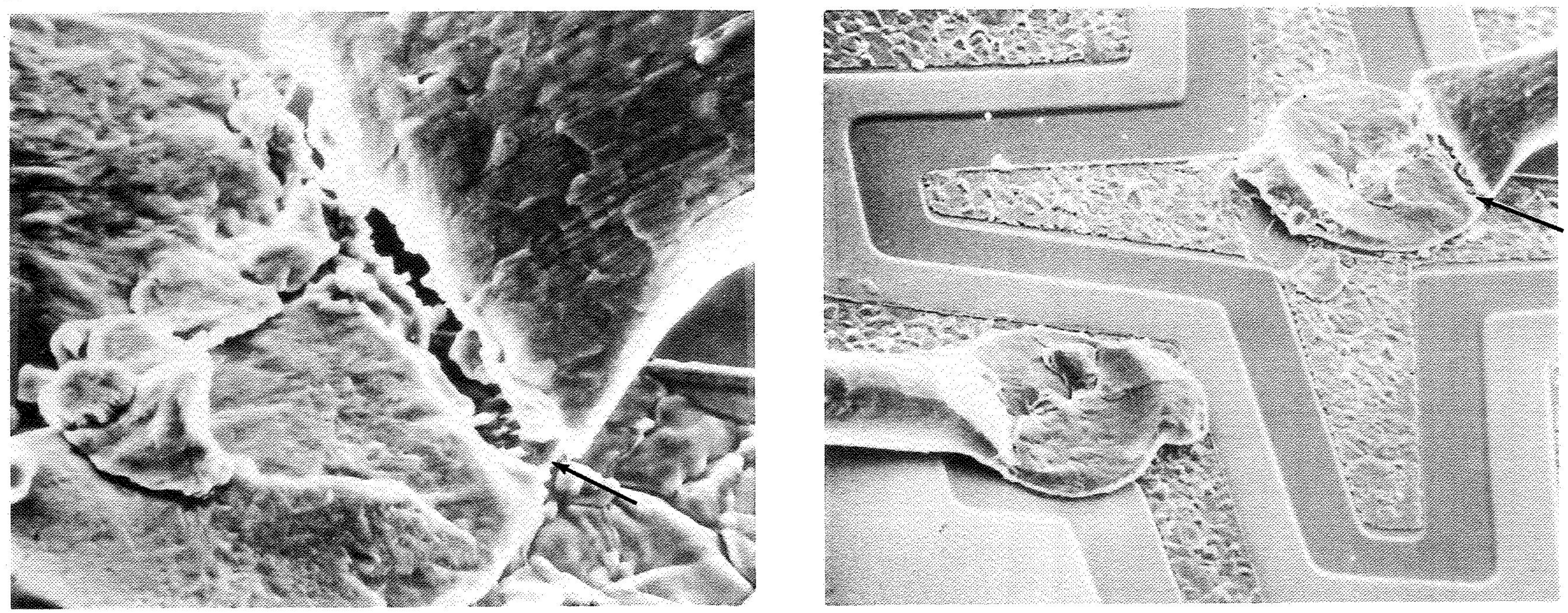


Figure 5. Manufacturer "A" 2N2222A, From Ignition Phase Timer, T. C. Wedge Bond. Emitter Bond Failed After 2240 Power Cycles

950X 480X

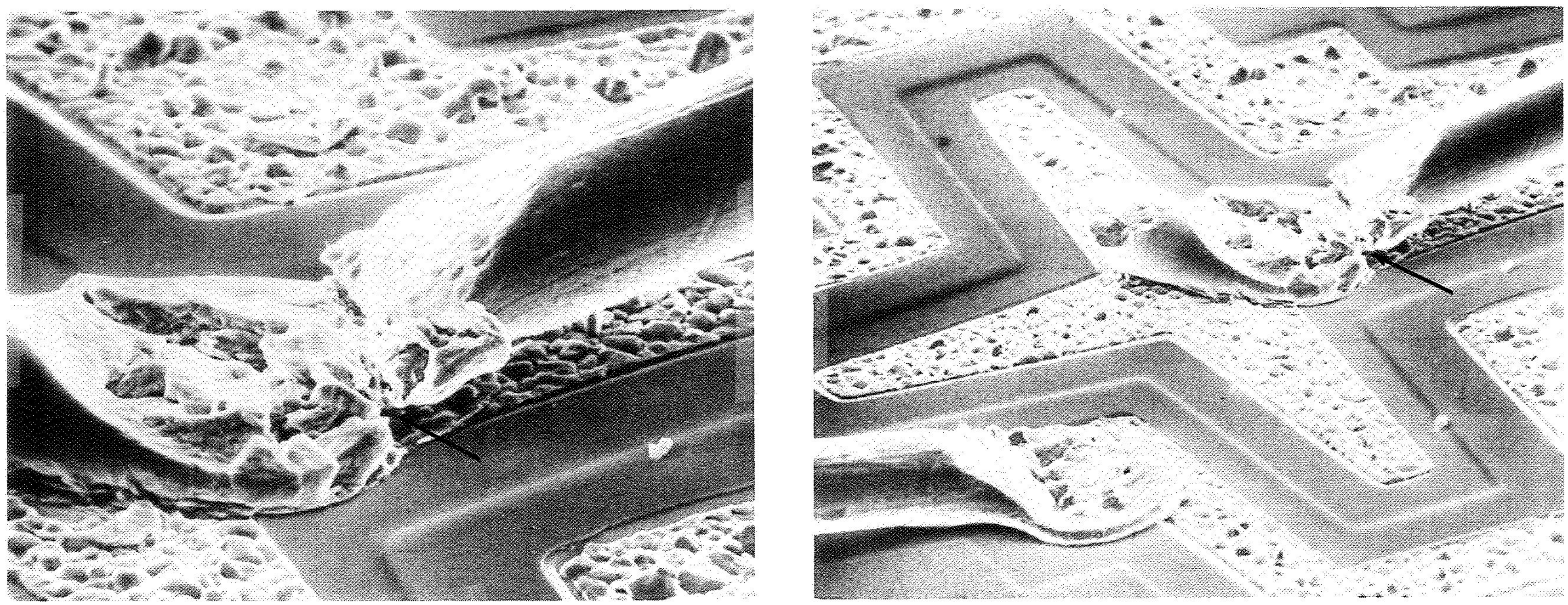


Figure 6. NA5-27473 (2N2222A), T.C. Wedge Bond.
Emitter Bond Failed After 4632 Power Cycles

1100X

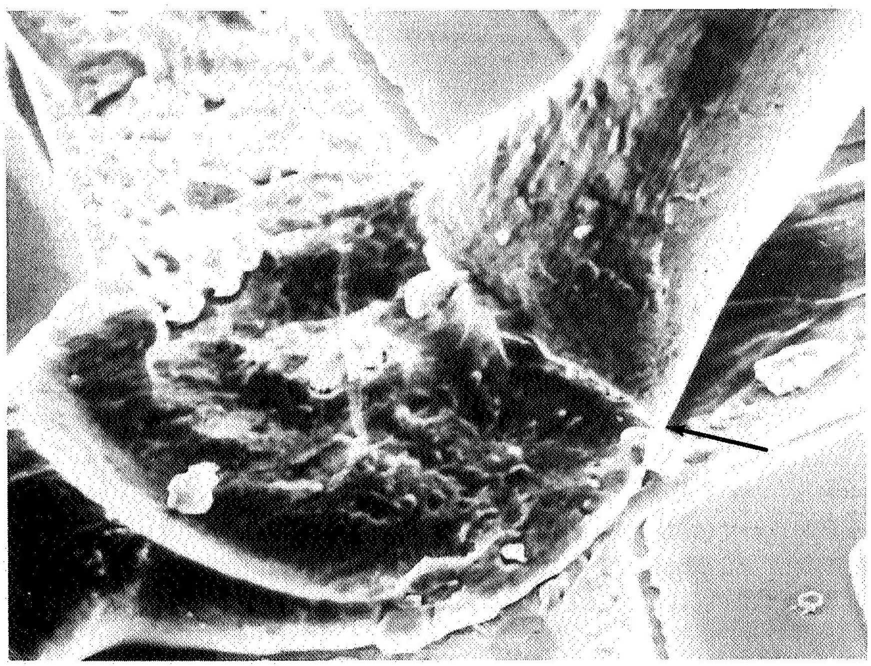


Figure 7. Manufacturer "A" 2N2222A, T.C. Wedge Bond, Emitter Bond, Microcracks at Heel After 4700 Power Cycles. Device Electrically Still Good.

To establish the extent to which thermal deformation caused by the temperature differential (ΔT) in the systems produces motion of the Al interconnecting wire, power cycling tests were conducted at various combinations of power levels, current, and cycling time. Such tests were performed in 1966, by A. C. Electronics. A summary of the test results is shown in table 1. Since this data was made available to us, the tests were not repeated.

Figure 8 shows that lead movement was caused by the combination of Joulian heating in the leads (I^2R) and power dissipation in the chip. In fact, emitter lead movement was visually detected under 80X magnification at 204 mW of power dissipation and a collector current of 365 mA. At 400 mW, only a collector current of 90 mA was required to cause the same movement. The transistor under test was manufactured by Manufacturer "A", part number 1006323 having 1-mil Al interconnecting lead wires.

A. C. Electronics found that the current required to fuse 1-mil Al lead wire ranges from 1.2 to 1.9 amperes depending on the lead length, the shorter the lead, the greater the current capability. A 60-mil-long lead, which is typical for this transistor, fused at a current of 1.4 amperes.

C. POWER CYCLING TEST

Since the power cycling tests performed by MSFC confirmed the studies made by A. C. Electronics, Motorola's Applied Science Department, Massachusetts Institute of Technology and Raytheon Company's Space and Information Systems Division, no further investigation was performed. Instead, the effort at MSFC was directed towards the establishment of operation limits for the present devices. MSFC also performed a SEM study of bond degradation.

To establish operation limits, parallel tests were conducted by MSFC and Manufacturer "A". At the request of MSFC, Manufacturer "A" began power cycling tests at various operating conditions on devices using 0.001-inch diameter Al interconnecting lead wire and T.C. wedge bonds, while MSFC began power cycling tests on devices using 0.001-inch diameter Al wire ultrasonically bonded, and devices using 0.0007- to 0.001-inch diameter gold (Au) T.C. bonds. Table 2 summarizes the results of the tests performed by Manufacturer "A". The tests performed by MSFC are summarized in table 3.

Table 1. Power Cycling Test Results

Condition	P_D	I_C	Frequency	Duty Cycle	Pulse Width
I	420 mW	520 mA	1 Hz	50%	1/2 Sec.
II	720 mW 1,280 mW 1,170 mW 310 mW	20 mA 80 mA 90 mA 125 mA	1 Hz 1 Hz 1 Hz 1 Hz.	50%* 50% 50% 50%	1/2 Sec. 1/2 Sec. 1/2 Sec. 1/2 Sec.
III	7 mW	10 mA	1 Hz	50%	1/2 Sec.
IV	420 mW 420 mW 420 mW	550 mA 550 mA 550 mA	10 Hz 10 Hz 10 Hz	2%* 5% 10%	2 m Sec. 5 m Sec. 10 m Sec.
V	420 mW	550 mA	60 Hz	50%	8.3 m Sec.

*No movement was detected.

NOTE: Power cycling conditions under which emitter lead measurement is detectable under 80X magnification.

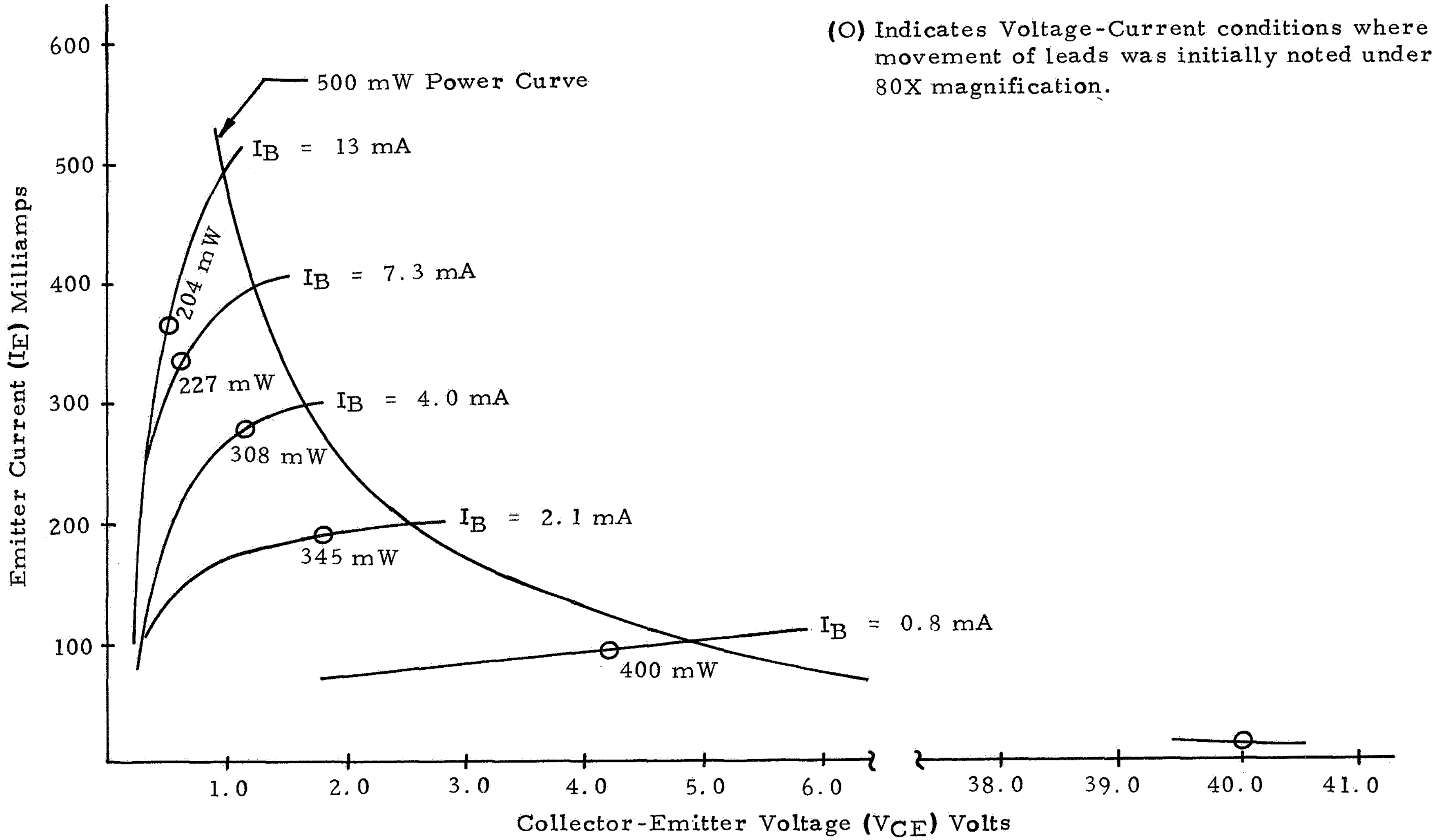


Figure 8. Emitter Current vs Collector - Emitter Voltage at Repetition Rate of 1 Hz.

Table 2. Summary of Power Cycling Tests
(Aluminum Thermocompression Wedge Bonds)

Manufacturer	Device Type	Date Code	Quantity	Test Conditions P_D	Test Conditions I_C	Failures At Cycles	Total Failures	Wire Type
A	JAN2N2222A	6927A	85	500mW	16.5mA	0 @ 1410, 2 @ 2082 2 @ 3090, 4 @ 4098 4 @ 5178, 1 @ 6042 0 @ 8058	13	Al
A	JAN2N2222A	6927A	247	500mW	50mA	0 @ 240, 5 @ 1600 3 @ 3280, 19 @ 4720 11 @ 6400, 5 @ 8080 0 @ 9760, 9 @ 11440	52	Al
A	JAN2N2222A	6927A	750	165mW	50mA	0 @ 240, 10 @ 1600 18 @ 3280, 3 @ 4720 2 @ 6160, 3 @ 7840 1 @ 9520, 0 @ 12880 1 @ 14080, 0 @ 23640	38	Al
A	JAN2N2222A	6927A	500	335mW	50mA	0 @ 240, 10 @ 1600 7 @ 3280, 5 @ 4720 1 @ 6400, 2 @ 8080 1 @ 9760, 1 @ 11440 0 @ 17440, 4 @ 18880 8 @ 22960	39	Al
A	JAN2N2222A	6927A	500	165mW	16.5mA	1 @ 588, 0 @ 3078 0 @ 5958, 1 @ 6822 0 @ 7502, 1 @ 8942 0 @ 21902	3	Al
A	JAN2N2222A	6927A	500	335mW	16.5mA	4 @ 588, 3 @ 1958 2 @ 3078, 0 @ 5958 2 @ 6822, 3 @ 7502 3 @ 9182, 1 @ 10862 5 @ 11870, 1 @ 13310 7 @ 14750, 3 @ 16190 5 @ 17630, 4 @ 22630	43	Al

NOTE: All devices were power cycled at a rate of 10 cycles-per-hour (3 minutes on, and 3 minutes off). Prior to 588 cycles the tests were performed at a rate of 6 cycles-per-hour (5 minutes on, and 5 minutes off). All failures were analyzed and found to be an open or broken lead at the heel of the semiconductor bonds.

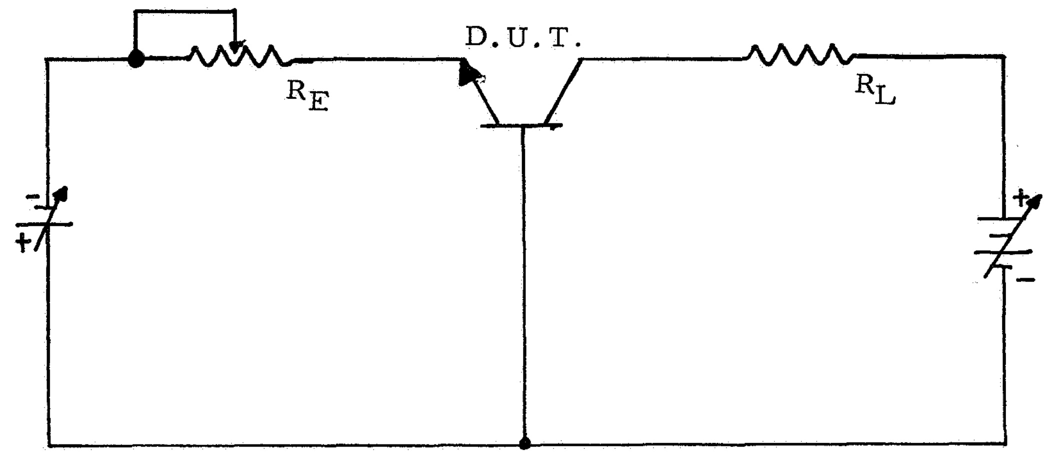
Table 3. Summary of Power Cycling Tests
(Aluminum Ultrasonic and Gold Thermocompression Bonds)

Manufacturer	Device Type	Date Code	Quantity	Test Conditions P_D	Test Conditions I_C	Failures & Cycles (See Note 3)	Total Failures	Wire Type
B	2N2222A (Group 1)	6949 7007	69	500mW	50mA (See Note 1)	0 @ 8000, 1 @ 8190 1 @ 8540, 2 @ 10020 4 @ 11400, 1 @ 11600 1 @ 13880, 1 @ 14500 2 @ 14830, 1 @ 16500 2 @ 17290, 1 @ 17600 1 @ 18000, 1 @ 18410 1 @ 18840, 1 @ 19370 2 @ 19850, 2 @ 21020 1 @ 22710, 1 @ 23200 1 @ 23390, 1 @ 23690 1 @ 24580, 2 @ 25330 1 @ 25810, 3 @ 26790 1 @ 27710, 1 @ 28200 1 @ 29510, 1 @ 29670 1 @ 31110, 1 @ 31750 1 @ 33530, 1 @ 35610 1 @ 38140, 1 @ 43,370 1 @ 48620 1 @ 51240, 2 @ 61320	50	Al
B	2N2222A (Group 2)	7007	25	100mW	50mA (See Note 2)	0 @ 82530, 1 @ 83070 0@ 135660	1	Al
B	2N2222A (Group 3)	7007	25	25mW	10mA (See Note 2)	0 @ 138660	0	Al
B	2N2222A (Group 4)	7007	25	20mW	10mA (See Notes 2&4)	0 @ 135660	0	Al
C	2N2222A (Group 5)	----	19	500mW	50mA (See Note 1)	0 @ 50320	0	Au
D	JAN2N2222A (Group 6)	----	13	500mW	50mA (See Note 1)	0 @ 87150	0	Au
C	S2N910 (Group 7)	6750 6812 6815	49	500mW	50mA (See Note 1)	0 @ 72120	0	Au
E	S2N718 (Group 8)	6450 6520	49	500mW	50mA (See Note 1)	0 @ 41900, 1 @ 42060 0 @ 72930	1	Au
D	S2N718 (Group 8)	6948	49	500mW	50mA (See Note 1)	0 @ 19820, 1 @ 19880 0 @ 72930	1	Au

NOTE: 1. All devices were power cycled at a rate of 10 cycles-per-hour (3 minutes on, and 3 minutes off).
2. All devices were power cycled at a rate of 30 cycles-per-hour (1 minute on, and 1 minute off).
3. All failures were analyzed and found to be an open or broken lead at the heels of the bonds.
4. Devices were in a steady-state environmental condition of $85^{o} \pm 3^{o}C$ during both the on and off period of power cycling.

1. MSFC TEST PROGRAM

The following groups of devices were power cycled at conditions specified below and using the circuit configuration shown below. A summary of power cycling tests is given in table 3.



a. Ultrasonic Bonding Systems of Al wire to Metallization

(1) Group 1

Sample Size = 69 2N2222A transistors
P_T = 500 mW (Maximum Rated Power)
T_A = $25^o \pm 3^oC$
I_C = 50 mA and V_{CE} = 10 V
Power on = 3 minutes
Power off = 3 minutes
Total number of cycles = 83,070

(2) Group 2

Sample Size = 25 2N2222A transistors
P_T = 100 mW
T_A = $25^o \pm 3^oC$
I_C = 50 mA and V_{CE} = 2 V
Power on = 1 minute
Power off = 1 minute
Total number of cycles = 111,750

(3) Group 3

Sample Size = 25 2N2222A transistors
P_T = 25 mW
T_A = $25^o \pm 3^oC$
I_C = 10 mA and V_{CE} = 2.5 V
Power on = 1 minute
Power off = 1 minute
Total Number of cycles = 113,460

(4) Group 4

Sample Size = 25 2N2222A transistors
P_T = 20 mW
T_A = $85^o \pm 3^oC$ (oven)
I_C = 10 mA and V_{CE} = 2 V
Power on = 1 minute
Power off = 1 minute
Total number of cycles = 113,460

NOTE: In group 4 the devices are in a steady-state environmental condition of $85^o \pm 3^oC$ during both the on and off period of power cycling.

b. T.C. Bonded Systems of Au wire to Al Metallization

(1) Group 5

Sample Size = 19 2N2222A transistors
P_T = 500 mW (Maximum Rated Power)
T_A = $25^o \pm 3^oC$
I_C = 50 mA and V_{CE} = 10 V
Power on = 3 minutes
Power off = 3 minutes
Total number of cycles = 44,590

(2) Group 6

Sample Size = 13 2N2222A transistors
P_T = 500 mW (Maximum Rated Power)
T_A = $25^o \pm 3^oC$

I_C = 50 mA and V_{CE} = 10 V
Power on = 3 minutes
Power off = 3 minutes
Total number of cycles = 78,750

(3) Group 7

Sample Size = 49 S2N910 transistors
P_T = 500 mW (Maximum Rated Power)
T_A = $25^o \pm 3^oC$
I_C = 50 mA and V_{CE} = 10 V
Power on = 3 minutes
Power off = 3 minutes
Total number of cycles = 63,040

(4) Group 8

Sample Size = 98 S2N718 transistors
P_T = 500 mW (Maximum Rated Power)
T_A = $25^o \pm 3^oC$
I_C = 50 mA and V_{CE} = 10 V
Power on = 3 minutes
Power off = 3 minutes
Total Number of Cycles = 67,200

2. THE METHOD OF LEAST SQUARES

A plot of cumulative percent of failures versus device cycles operated for devices operated under the same power current and repetition rates is shown in figure 9. The data for the Manufacturer "A" 2N2222A (Al) T.C. bond were not well correlated. The least squares method was used to determine the slope of the correlated data.

Table 4 shows how the least squares line was fitted to the data.

In order to have the line $y^1 = a+bx$ satisfy the criterion of least squares, the constants (a) and (b) must be such that

$$\sum_{i=1}^{n} (yi - yi^1)^2 \text{ is as small as possible.}$$

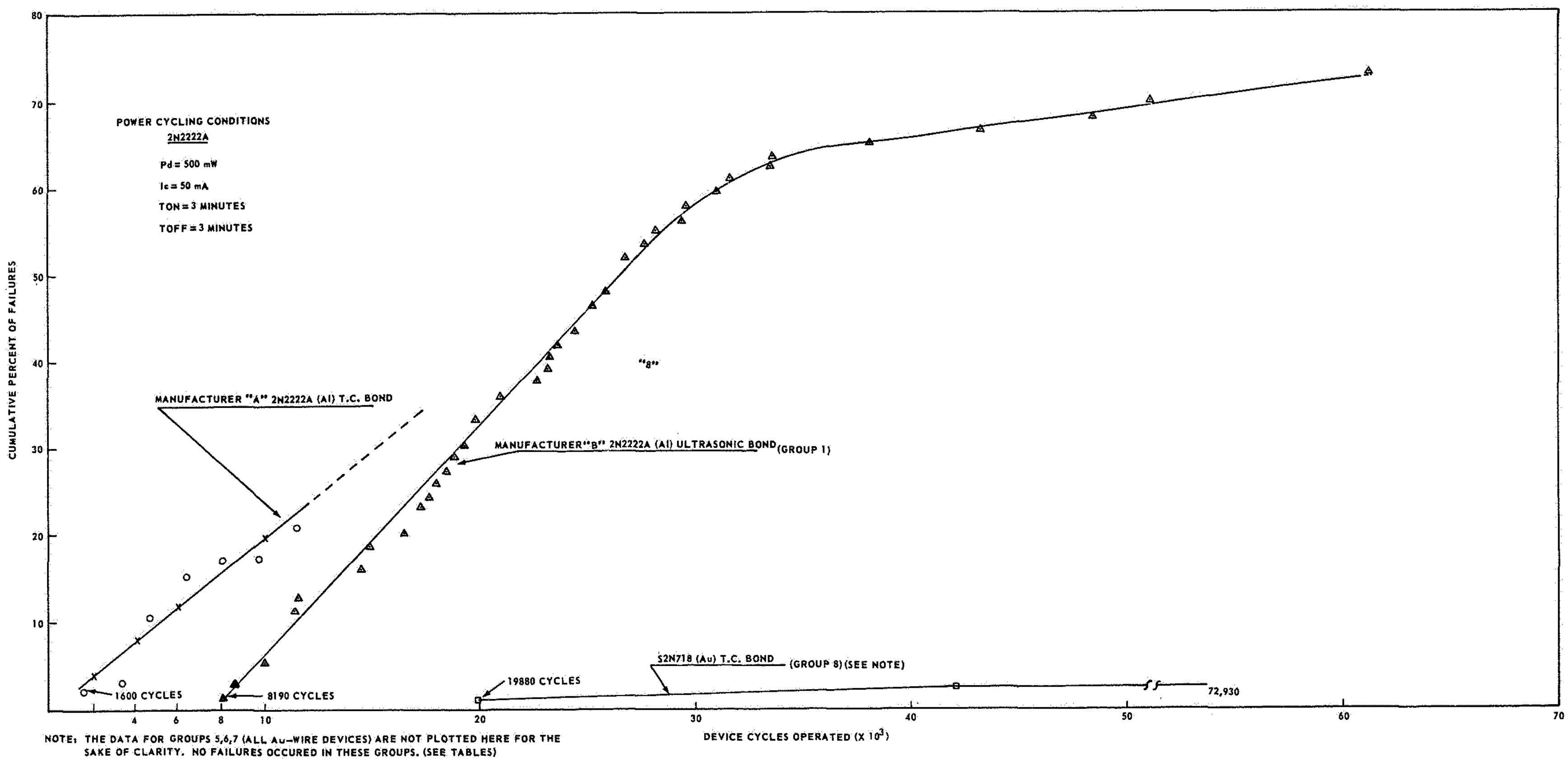


Figure 9. Percentage of Failure

Table 4. Least Squares Method Fitted to Manufacturer "A" Data

n Number of Plotted Points	N Number of Devices Failed	xi Number of Cycles per Device	yi Cumulative % of Failures $\% = \frac{N \cdot 100}{247}$	xi^2	xiyi
1	5	1,600	2.0	2,560,000	3,200
2	3	3,280	3.2	10,758,400	10,496
3	19	4,720	10.9	22,278,400	51,448
4	11	6,400	15.4	40,960,000	98,560
5	5	8,080	17.4	65,286,400	140,592
6	0	9,760	17.4	95,257,600	169,824
7	9	11,440	21.0	130,873,600	240,240
TOTAL		45,280	87.3	$36,797 \times 10^4$	714,360

NOTE: Total number of devices = 247

The constants (a) and (b) can be obtained by solving the following two simultaneous equations, called the normal equations:

$$\Sigma yi = a \cdot n + b \cdot \Sigma xi$$

$$\Sigma xiyi = a \cdot \Sigma xi + b \cdot \Sigma xi^2$$

where:

$$b = \frac{n\,(\Sigma xiyi) - (\Sigma xi)\,(\Sigma yi)}{n(\Sigma xi^2) - (\Sigma xi)^2} = \frac{7\,(714{,}360) - 45{,}280\,(87.3)}{7\,(36{,}797 \times 10^4) - (2050 \times 10^6)}$$

$$= 19.9 \times 10^{-4}$$

$$a = \frac{\Sigma yi - b(\Sigma xi)}{n} = \frac{(87.3) - (19.9 \times 10^{-4})\,(45{,}280)}{7} = -0.4$$

therefore:

$$y1 = -0.4 + (19.9 \times 10^{-4})x$$

x	y1
0	- 0.4
2,000	3.58
4,000	7.56
6,000	11.54
10,000	19.5

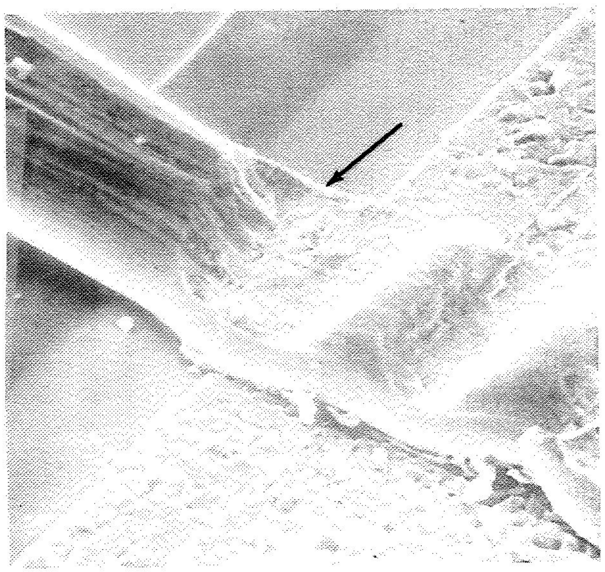
Although the Manufacturer "B" ultrasonic bonds did not fail as early as the Manufacturer "A" T. C. bonds, the rate of failure of the Manufacturer "B" ultrasonic bonds after the initial failure is about the same as that experienced by the Manufacturer "A" T. C. bonds. This is illustrated by the fact that the two plots are nearly parallel.

3. SEM

Three devices from group 1 (serial numbers 74, 75, and 76) were decapped and analyzed by the SEM, before and during power cycling as well as after failure.

Failure of device serial number 74, which is illustrated in figures 10 through 12, was attributed to an open base post bond after 16,200 power cycles. The failure mode is shown in figure 12.

Base, 1400X



Emitter, 1560X

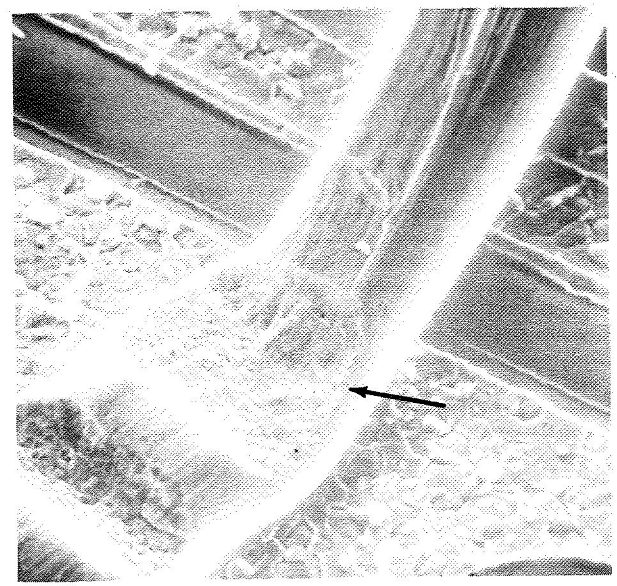


Figure 10. Manufacturer "B" 2N2222A, Serial Number 74, Die Side Bond, Ultrasonic. No Evidence of Microcracks at The Heel After 3152 Power Cycles

Base, 1150X

Emitter, 1150X

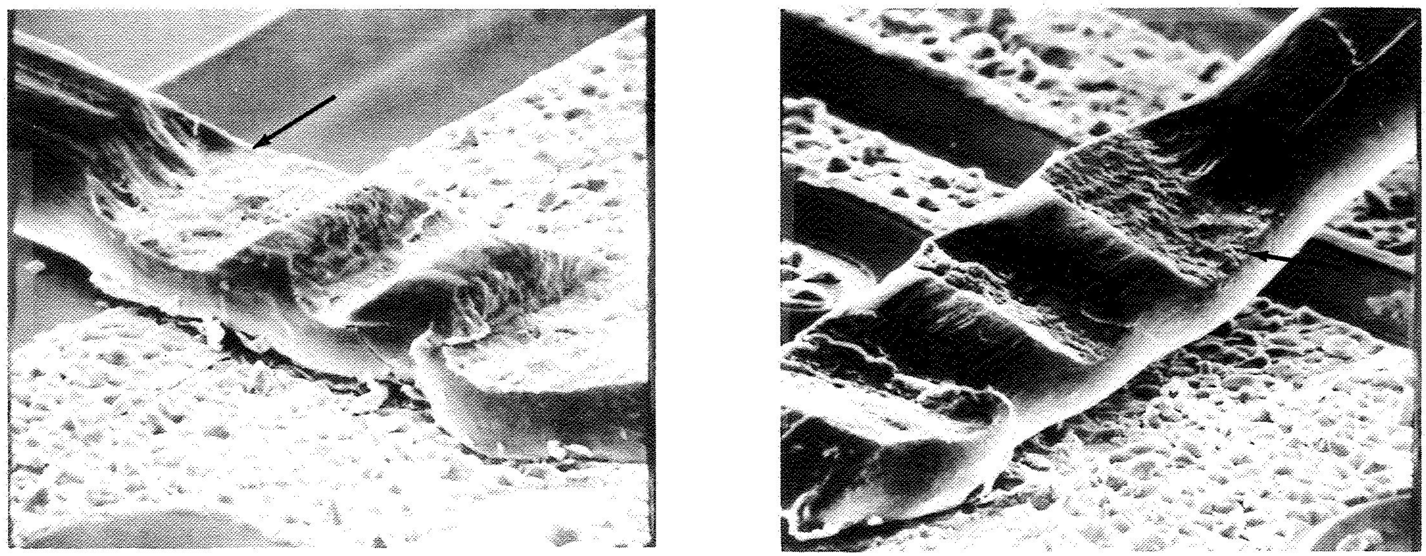


Figure 11. Manufacturer "B" 2N2222A, Serial Number 74, Die Side Bond, Ultrasonic. No Evidence of Microcracks at The Heel After 16,200 Power Cycles

230X

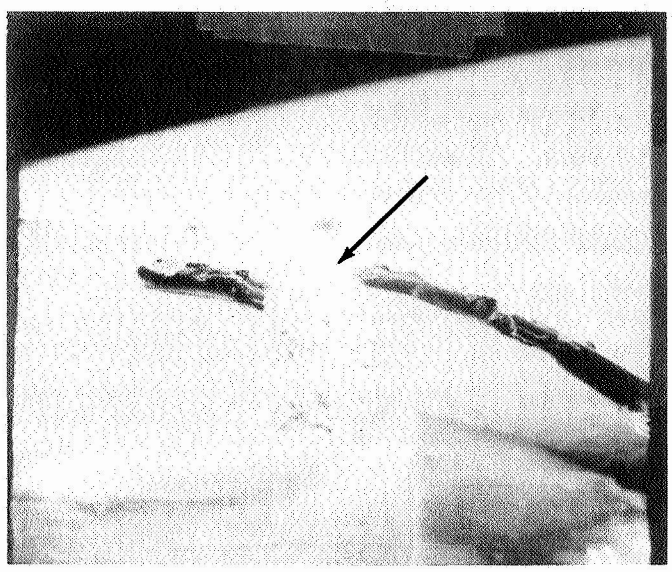


Figure 12. Manufacturer "B" 2N2222A, Serial Number 74, Base Post Bond, Ultrasonic. Open at The Heel After 16,200 Power Cycles.

Failure of the device, serial number 75, was attributed to open emitter and base bonds at the heel, as shown in figures 19 and 20. It is also interesting to note the deterioration (granular appearance) in the Al metallization as function of the power cycling. (See figures 13 through 15.)

Base, 1250X

Emitter, 1250X

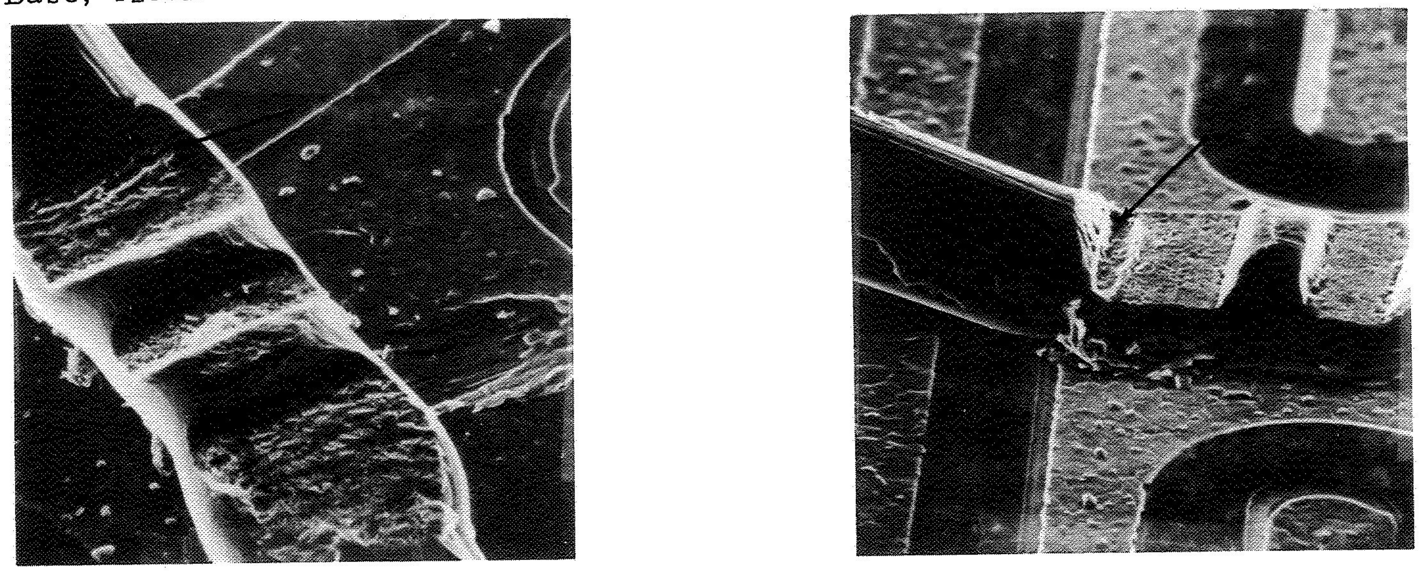
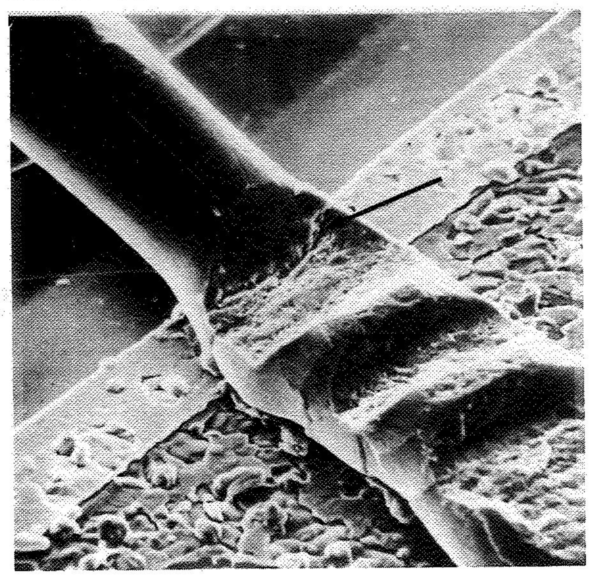


Figure 13. Manufacturer "B" 2N2222A, Serial Number 75, Die Side Bond, Ultrasonic. Evidence of Microcracks at The Heel Before Power Cycling

Base, 1250X



Emitter, 1250X

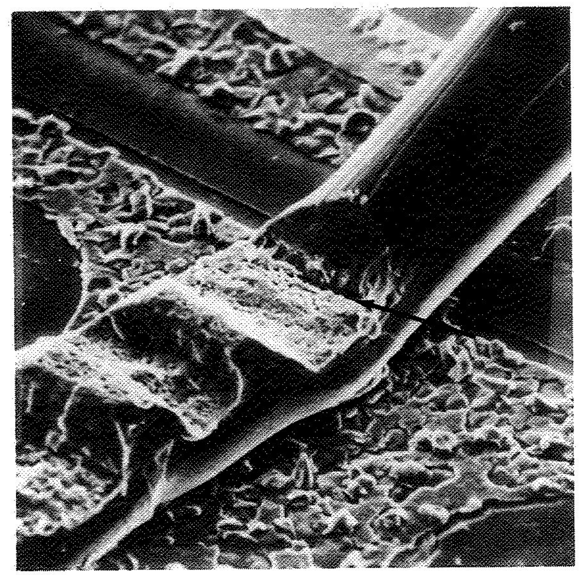
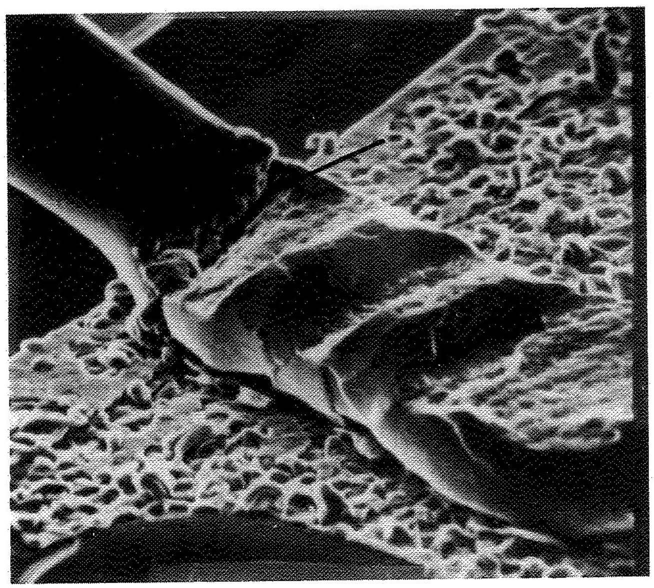


Figure 14. Manufacturer "B" 2N2222A, Serial Number 75, Die Side Bond, Ultrasonic. Microcracks Depth Increased After 3152 Power Cycles

Base, 1250X



Emitter, 1250X

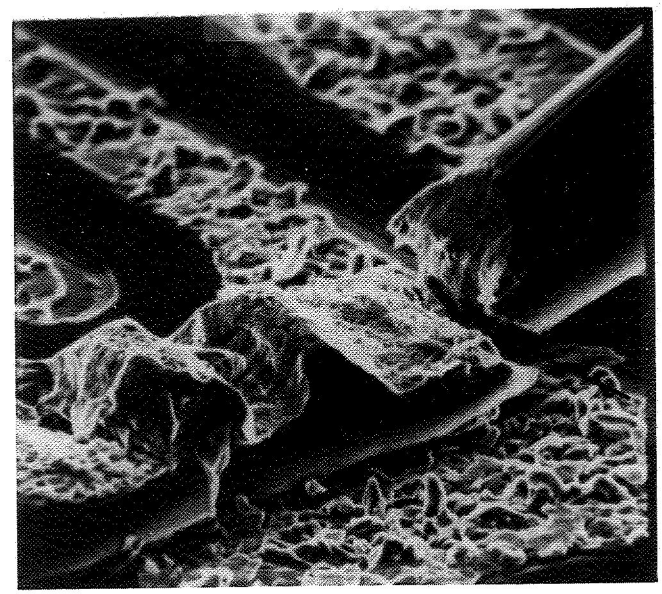


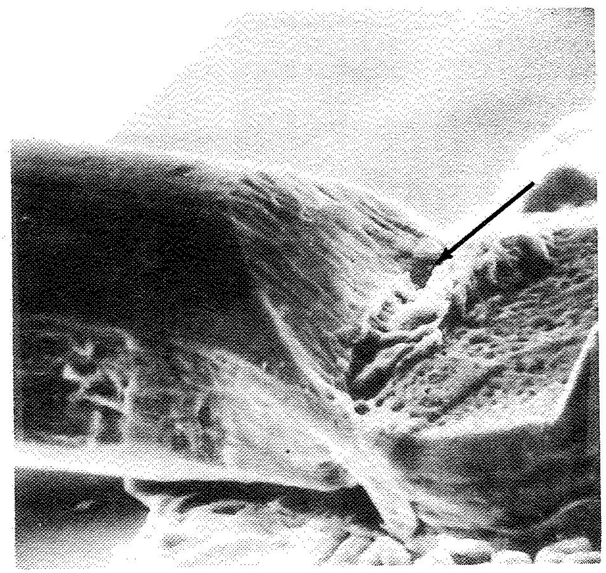
Figure 15. Manufacturer "B" 2N2222A, Serial Number 75, Die Side Bond, Ultrasonic. Open at Heel After 14, 500 Power Cycles

Device, serial number 76, exhibited the same failure mode and mechanism as device serial number 75. Cracks in the heel of the bonds were found also, before the power cycling test. Figures 16 through 18 depict clearly the increasing depth of the microcracks as a function of the power cycling.

1560X

Figure 16. Manufacturer "B" 2N2222A, Serial Number 76, Emitter Die Side Bond, Ultrasonic. Evidence of Microcracks at the Heel Before Power Cycling

Base, 3000X



Emitter, 1560X

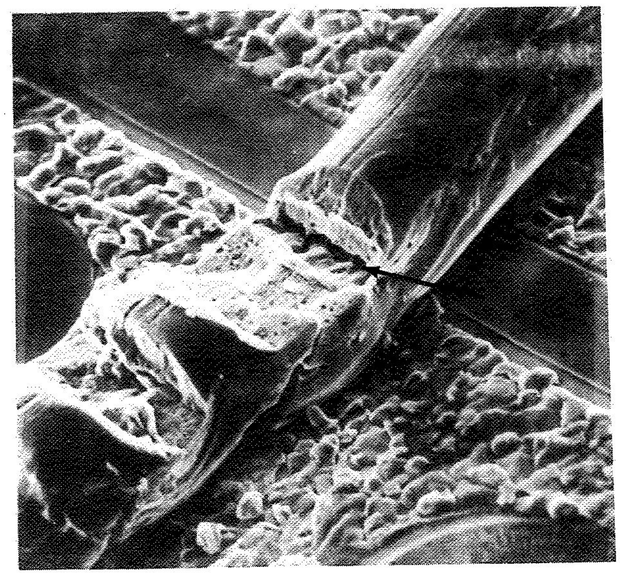
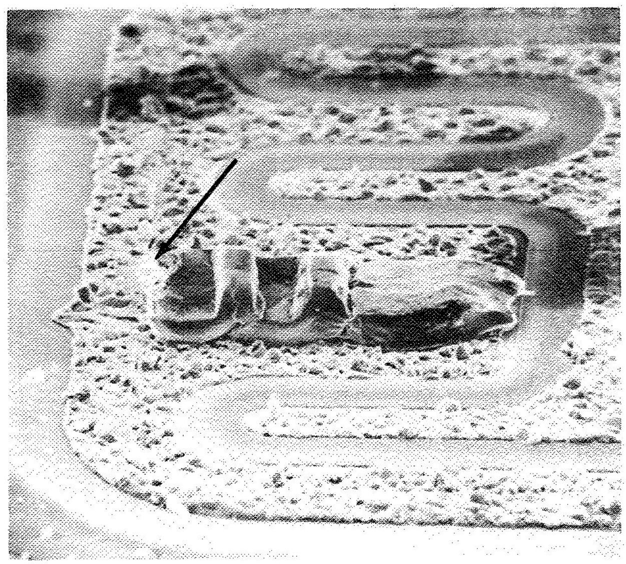


Figure 17. Manufacturer "B" 2N2222A, Serial Number 76, Die Side Bond, Ultrasonic. Microcracks Depths Increased After 3152 Power Cycles

Base, 570X



Emitter, 630X

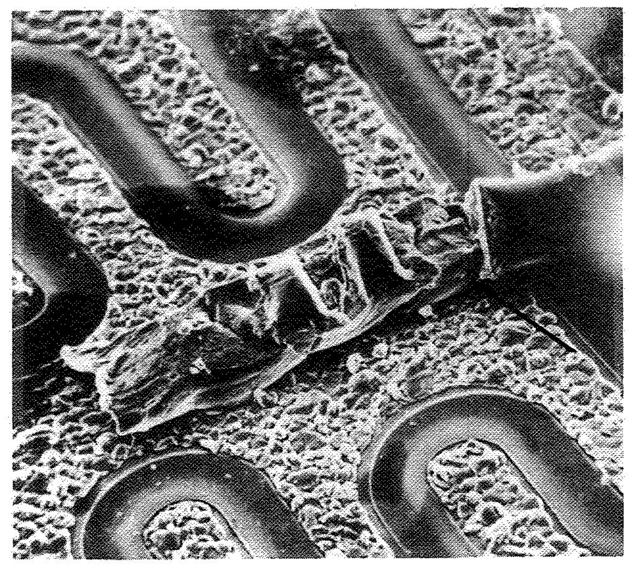


Figure 18. Manufacturer "B" 2N2222A, Serial Number 76, Die Side Bond, Ultrasonic. Open at The Heel After 18,000 Power Cycles

The post wire bonds in all three devices were good with the exception of the base post bond of device serial number 74.

Also, at the end of the power cycling test, a random sample was taken from each group of the devices that survived the test. The sample was analyzed by the SEM and it was found that electrically-good ultrasonically bonded devices had deep microcracks at the heel of the bonds, such that the electric continuity was about to be broken. It is interesting to note that degradation of bond integrity is a function of the power and current level, as well as repetition rates. When examined under the SEM, devices from groups 1, 2, and 3 appear as shown in figures 19 through 21. It can be noted that the devices in groups 2 and 3 which were power cycled under less strenuous conditions (power current and repetition rates), when compared to group 1, did not exhibit bond degradation at the heel after 133,430 cycles. The microcracks or tool marks shown in figures 19 through 21 have the same appearance and depth as shown in previous photographs for devices scanned with the SEM before the power cycling test.

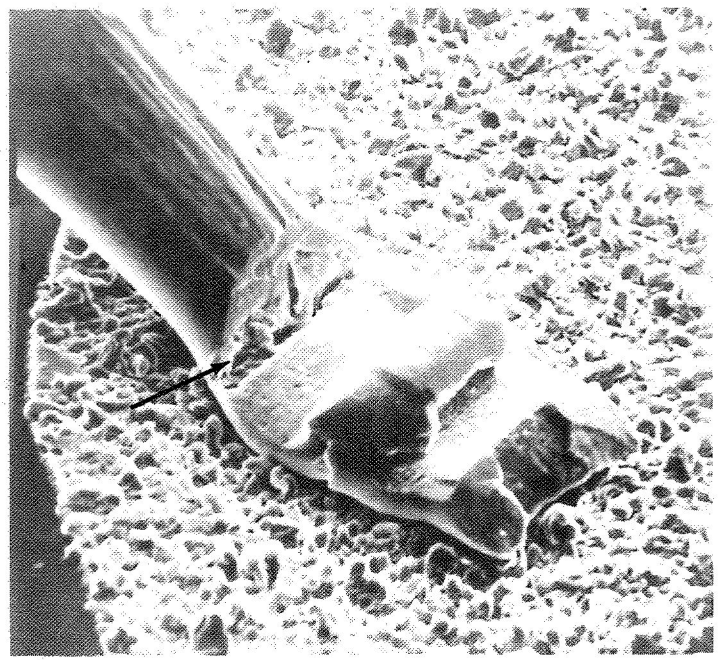
4. <u>BOND PULLING TEST</u>

At the end of the power cycling test, a bond-pull test was performed to investigate the strength of the 1-mil diameter Al and 1-mil diameter Au interconnecting lead wires. The pull test was performed on all bonds in the devices that underwent SEM analysis, plus all remaining devices of group 3. The pull test was performed using a Micro Bond Tester. A thin molybdenum wire hook was carefully positioned under the loop of the interconnecting lead wire about midway between the die bond and the post bond of the transistor mounted on a fixed stage. The hook was attached to a retained reading dynamometer which was motor-driven at a constant angular velocity to apply a uniform loading rate. The loading rate used to pull the 1-mil wire was 0.2 grams per second.

The failure loads for 1-mil Al lead wire in the TO-18 packages were found to be in the range of 3.0 to 4.0 grams for leads that are ultrasonically bonded to a system consisting of Al metallization on the die and Au-plated Kovar package posts. The failure loads for 1-mil Au lead wire in the TO-18 packages were found to be in the range of 4.5 to 5.5 grams for leads that are T.C. bonded in the same metallization system as above. The results of the bond pulling test are presented in table 5.

Device From Group 1

Base, 975X



Emitter, 975X

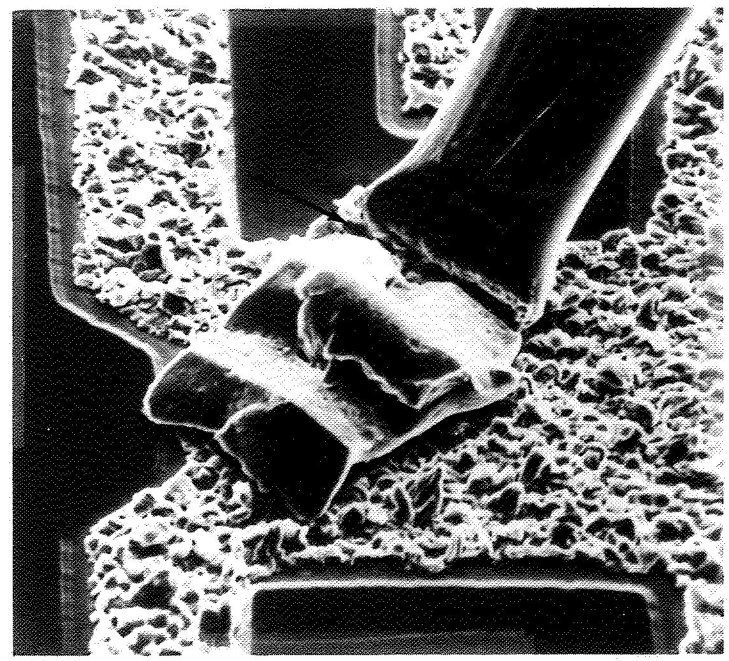
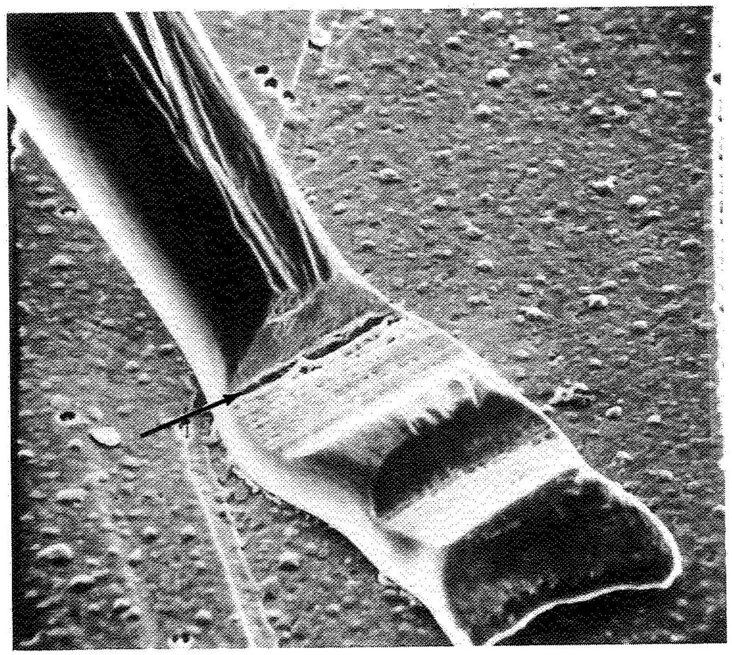


Figure 19. Manufacturer "B" 2N2222A, Serial Number 303, Die Side Bond, Ultrasonic. Microcracks at The Heel After 41,650 Cycles. Device Electrically Still Good

Device From Group 2

Base, 1000X



Emitter, 1000X

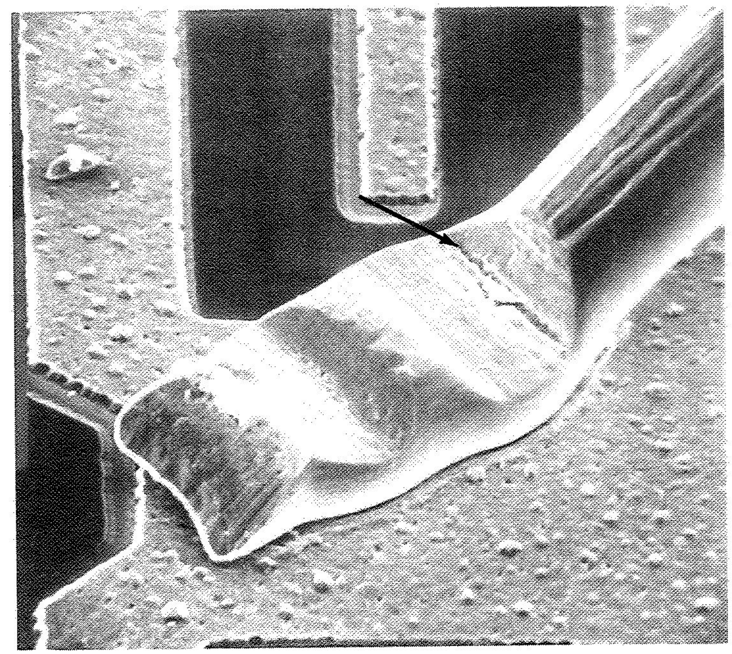
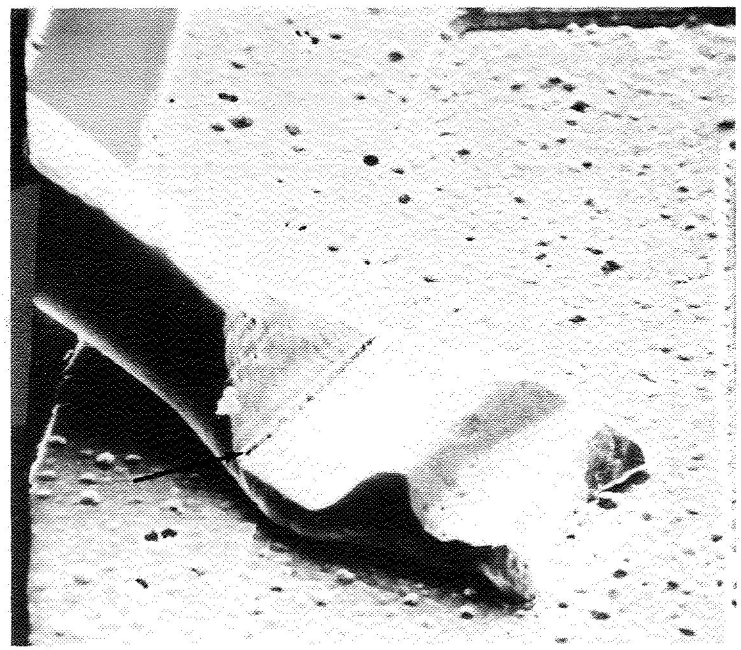


Figure 20. Manufacturer "B" 2N2222A, Serial Number 329, Die Side Bond, Ultrasonic. Microcracks at the Heel After 113,430 Cycles. Device Electrically Still Good.

Device From Group 3

Base, 950X



Emitter, 950X

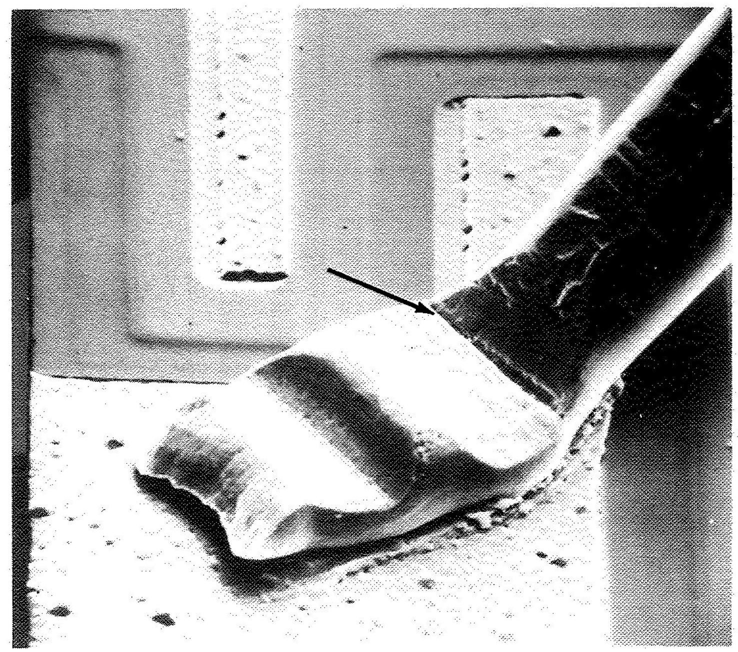


Figure 21. Manufacturer "B" 2N2222A, Serial Number 373, Die Side Bond, Ultrasonic. Microcracks At the Heel After 116,710 Cycles. Device Electrically Still Good.

Table 5. Bond Pulling Test

Transistor	Lot	Manufacturer	Power Cycles	Serial Number	Force in Grams		Wire Type and Bond Type	Pull Test Remarks	
					Emitter	Base		Emitter	Base
JAN2N2222A	Group 6	D	80,430		5.5	5.0	Au/TC	Wire Broke	Wire Broke
JAN2N2222A	Group 6	D	80,430		5.5	5.0	Au/TC	Wire Broke	Wire Broke
S2N910	Group 7	C	64,720		5.5	5.0	Au/TC	Wire Broke	Wire Broke
S2N910	Group 7	D	64,720		4.5	5.0	Au/TC	Wire Broke	Wire Broke
2N718A	Group 8	E	68,880		8.0	8.0	Au/TC	Bond Lifted	Bond Broke at Heel
2N718A	Group 8	E	68,880		1.5	7.5	Au/TC	Bond Broke at Post	Bond Lifted at Heel
2N718A	Group 8	D	68,880		8.0	8.0	Au/TC	Wire Broke	Wire Broke
2N718A	Group 8	D	68,880		8.0	8.0	Au/TC	Wire Broke	Wire Broke
2N2222A	Group 1	B	41,650	303	0	2.0	Al/US	Wire open at Heel	Bond Open at Heel
2N2222A	Group 1	B	41,650	322	2.5	0	Al/US	Bond Broke at Heel	Bond Open at Heel
2N2222A	Group 1	B	44,570	323	2.0	1.0	Al/US	Bond Broke at Heel	Bond Broke at Heel
2N2222A	Group 1	B	44,570	317	2.0	4.5	Al/US	Bond Broke at Heel	Wire Broke
2N2222A	Group 1	B	44,570	311	3.5	1.5	Al/US	Bond Broke at Heel	Bond Broke at Heel
2N2222A	Group 1	B	44,570	324	1.0	1.5	Al/US	Bond Broke at Post	Bond Broke at Heel
2N2222A	Group 1	B	44,570	318	2.5	0	Al/US	Bond Broke at Heel	Bond Broke at Heel
2N2222A	Group 2	B	135,660	341	4.0	3.5	Al/US	Bond Broke at Heel	Bond Broke at Post
2N2222A	Group 2	B	135,660	349	2.8	2.4	Al/US	Bond Broke at Heel	Bond Broke at Heel
2N2222A	Group 2	B	135,660	346	2.5	3.0	Al/US	Bond Broke at Heel	Bond Broke at Heel
2N2222A	Group 2	B	135,660	334	2.5	0	Al/US	Bond Broke at Heel	Bond Lifted From Post
2N2222A	Group 2	B	135,660	343	3.0	3.0	Al/US	Bond Broke at Heel	Bond Broke at Heel
2N2222A	Group 2	B	113,430	328	0	1.0	Al/US	Bond is Open at Post	Bond Broke at Heel
2N2222A	Group 2	B	113,430	329	4.0	3.0	Al/US	Wire Broke	Wire Lifted at Post
2N2222A	Group 3	B	116,710	372	2.5	4.0	Al/US	Bond Broke at Heel	Wire Broke
2N2222A	Group 3	B	116,710	373	3.0	2.0	Al/US	Bond Broke at Heel	Bond Broke at Heel

SECTION III. CONCLUSIONS

If significant microcracks or tool marks are present at the heel of T.C. wedge bonds on 1-mil Al wire, the bonds will fail when subjected to the stresses of low frequency power cycling. Failure may occur as early as 1600 cycles performed under the conditions described in figure 9, if the tool marks have caused a significant reduction in cross section of the wire. Devices subjected to the same power cycling conditions, but using 0.001 inch diameter Al wire ultrasonically bonded, may start to exhibit failures due to metal fatigue at approximately 8,000 cycles, if the above stated microcrack and tool mark conditions exist and they continue to fail with an approximately constant failure rate. After 45,000 cycles, the bonds in the surviving devices are so weak that they can be pulled apart with forces of 0 to 2.0 grams. Devices using 1-mil T.C. bonded Au interconnecting wire withstood the same power cycling conditions much better than either T.C. or ultrasonically bonded Al wire. Out of a total of 179 Au wire devices tested (groups 5, 6, 7, and 8) there were two failures, one at 19,880 cycles and another at 42,060 cycles. There was virtually no degradation in the Au wire bond strength as a result of power cycling. This is demonstrated by the bond-pull tests where all bonds withstood forces of 4.5 grams or greater except for one post bond that broke at 1.5 grams.

It is concluded that in order for devices using 1-mil Al wire to be used safely in power cycle type applications, very close control of the bonding process must be maintained to assure that tool marks, microcracks, or insufficient cross-sectional areas are not present on the heels of the bonds. The methods or degree of control necessary to prevent the above have not been determined, but a study is being initiated in an attempt to identify them. Also, by comparing groups 1, 2, and 3 of table 3, it is shown that devices in groups 2 and 3 which were power cycled at 100 mW or less exhibited a significantly lower failure rate as compared to group 1. It may be concluded that applications requiring less than 100 mW total dissipation at currents below 50 mA do not significantly degrade device reliability.

It is also concluded that the devices using 1-mil Au interconnecting wire are not significantly degraded when subjected to extensive power cycling.

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TECHNICAL MEMORANDUM TM X- 64566

APPROVAL

INVESTIGATION OF FATIGUE PROBLEM
IN 1-MIL DIAMETER THERMOCOMPRESSION
AND ULTRASONIC BONDING OF ALUMINUM WIRE

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

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